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TECHNICAL REPORT NO. 81-10

LAJITAS QUIET SITE NOISE STUDY

Sponsored by
Defense Advanced Research Projects Agency (DOD)
ARPA Order No. 2897 and 3328

TELEDYNE GEOTECH

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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Ambient earth noise in the 1-20 Hz band was studied at a site remote from cultural noise sources in southwest Texas. A small aperture, vertical component array was deployed which was specially designed to cope with the low noise conditions at the site. In the 1-10 Hz band, the power spectra at this site were about 10 db lower than previously reported spectra at other quiet sites. The noise appears to be stationary in time and space and is characterized by two peaks at 2 and 5 Hz, of which the sources are not known.

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LAJITAS QUIET SITE NOISE STUDY

by

Todd Li

Sponsored by
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AFTAC Project Authorization No.	VT/0703
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TELEDYNE GEOTECH
3401 Shiloh Road
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ABSTRACT

Ambient earth noise in the 1-20 Hz band was studied at a site remote from cultural noise sources in southwest Texas. A small aperture, vertical component array was deployed which was specially designed to cope with the low noise conditions at the site. In the 1-10 Hz band, the power spectra at this site were about 10 db lower than previously reported spectra at other quiet sites. The noise appears to be stationary in time and space and is characterized by two peaks at 2 and 5 Hz, of which the sources are not known. This site appears to be capable of providing source spectral information out to at least 10 Hz, provided that the appropriate instrumentation is available.

I. INTRODUCTION

The proposed comprehensive nuclear test ban treaty calls for the deployment of seismic monitoring systems at regional distances from potential test sites. In general, some type of signal enhancement technique will have to be applied to the data at these sites in order to detect and identify the sources of the relatively weak seismic signals generated by low magnitude earthquakes and underground nuclear explosions. Successful application of such a technique will usually require that both the system noise and the ambient earth noise are well-characterized. In the regional P-wave signal bandwidth (1-20 Hz), the magnitude and state of organization of the ambient earth noise is poorly known and is strongly site specific.

Clearly, sites that are remote from cultural noise sources are prime candidates for obtaining high signal-to-noise ratios. Thus, an experiment was designed to obtain a quantitative measure of the earth noise in the 1-20 Hz band at a site in southwestern Texas which meets that requirement. This site is located northwest of Big Bend National Park and is referred to in this report as the Lajitas site, after Lajitas, Texas, which is located about 14 km southwest of the site.

II. DESCRIPTION OF THE DATA COLLECTION SYSTEM

The Lajitas seismic array is located in southwestern Texas in Brewster County, approximately 14 km northeast of Lajitas and 11 km west of Terlingua (see figure 1). At this site, there is also a borehole seismometer operated by Southern Methodist University. The site is located on a horst block consisting primarily of Cretaceous limestone that is part of the Commanche Series.

Twelve short-period Geotech Model 18300 seismometers were installed at the site along with twelve Model 28470-65 long-period brick amplifiers, with Model 33330 preamplifiers, which were modified for short-period filters and the low noise conditions at the Lajitas site. A schematic block diagram of the data collection system is shown in figure 2. The frequency response of the system to a constant displacement input is shown in figure 3. The system includes 20 Hz low-pass filters.

The twelve seismometers were arranged in an approximate L-shaped array, as shown in figure 4, with one arm oriented north to south and the other arm extending eastward from the southern end. One seismometer extended fifty meters southwest of the center of the array. The limestone made it impractical to bury the seismometers, so they were placed on the surface and covered by plastic trash cans weighted by sand bags and rocks. The total aperture of the array is approximately 962 meters from seismometer one to twelve with a minimum spacing of 50 meters. The maximum-likelihood frequency-wavenumber response of the array is shown in figure 5.

The digital recording system was operated at a 40 sample/sec rate with 11-bit plus a sign bit quantization. These parameters provide a Nyquist frequency of 20 Hz and a nominal dynamic range of 66 db. The amplifiers were operated at near-maximum gains of 24 db and 30 db.

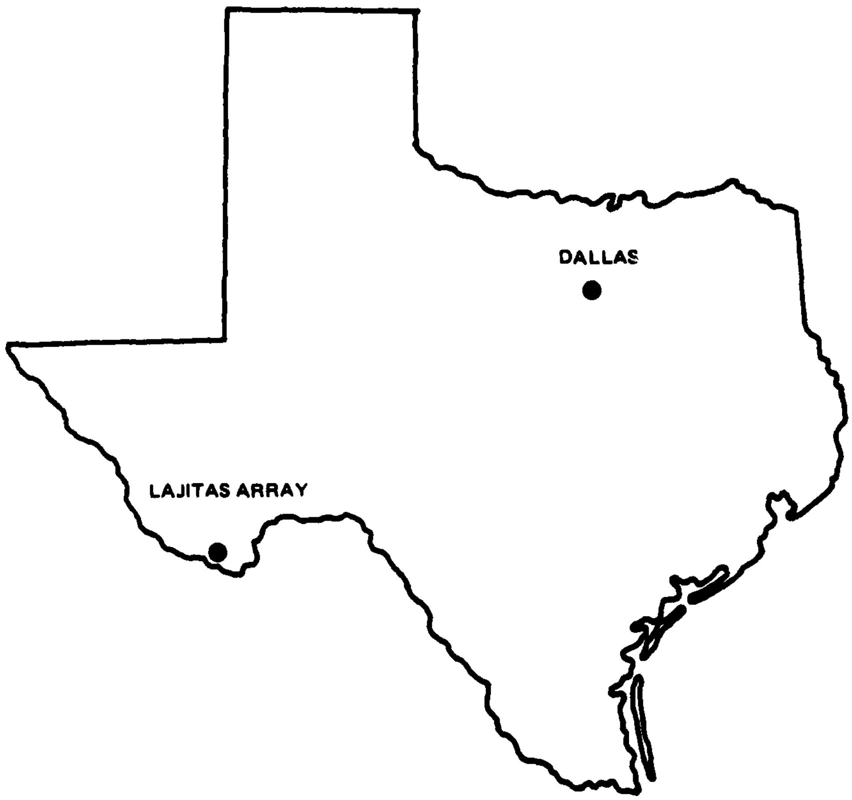

FIGURE 1. LOCATION MAP OF SEISMIC ARRAY AT LAJITAS, TEXAS

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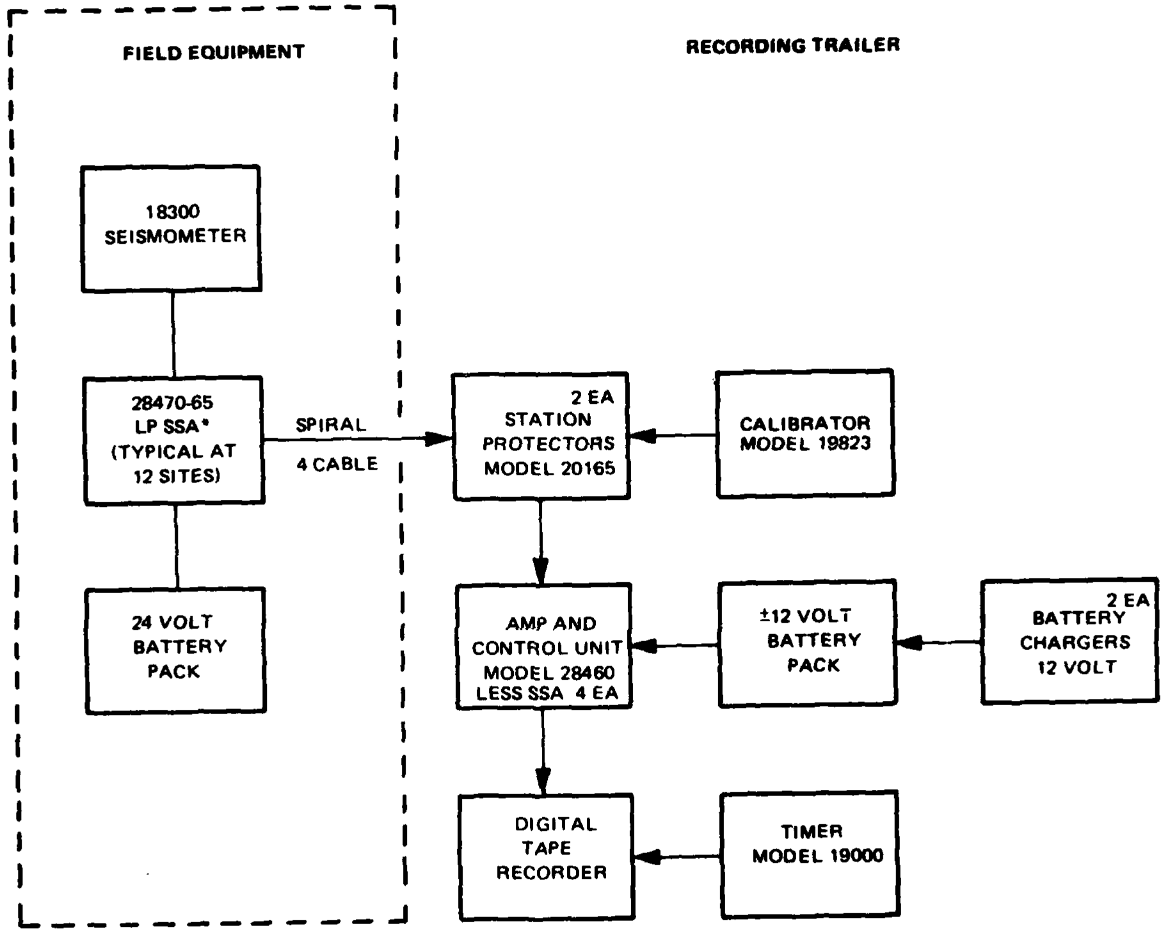

*12 EA LP SSA BRICKS WERE MODIFIED FOR LOW NOISE AND SP FILTERS.

FIGURE 2. BLOCK DIAGRAM OF THE LAJITAS ARRAY DATA COLLECTION SYSTEM

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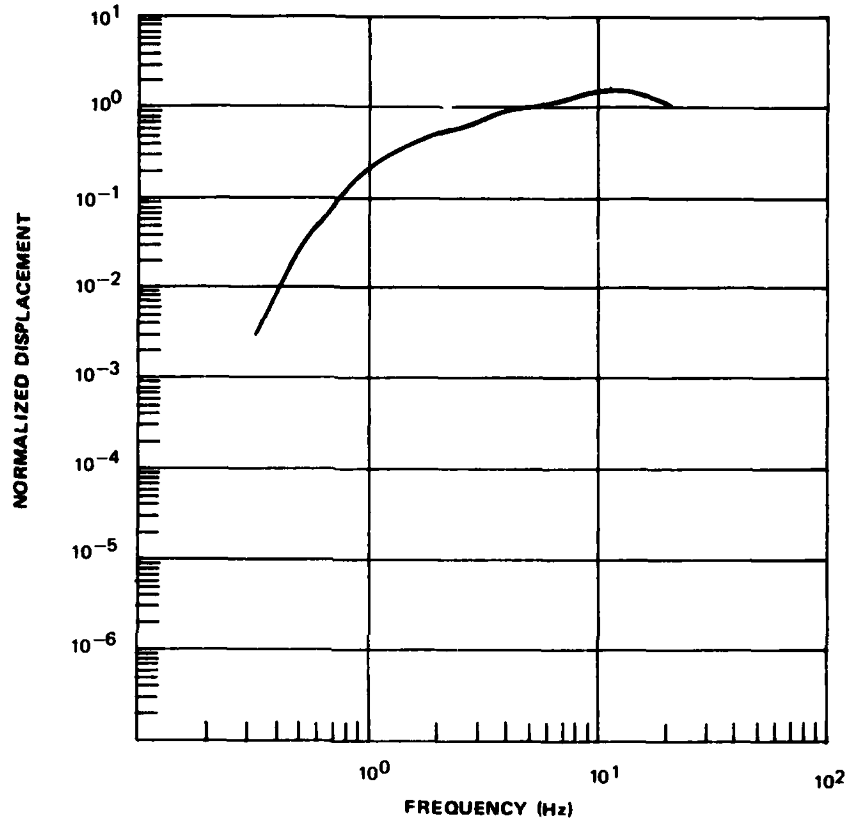

FIGURE 3. FREQUENCY RESPONSE OF THE DATA COLLECTION SYSTEM TO A CONSTANT DISPLACEMENT INPUT, NORMALIZED AT 5 Hz.

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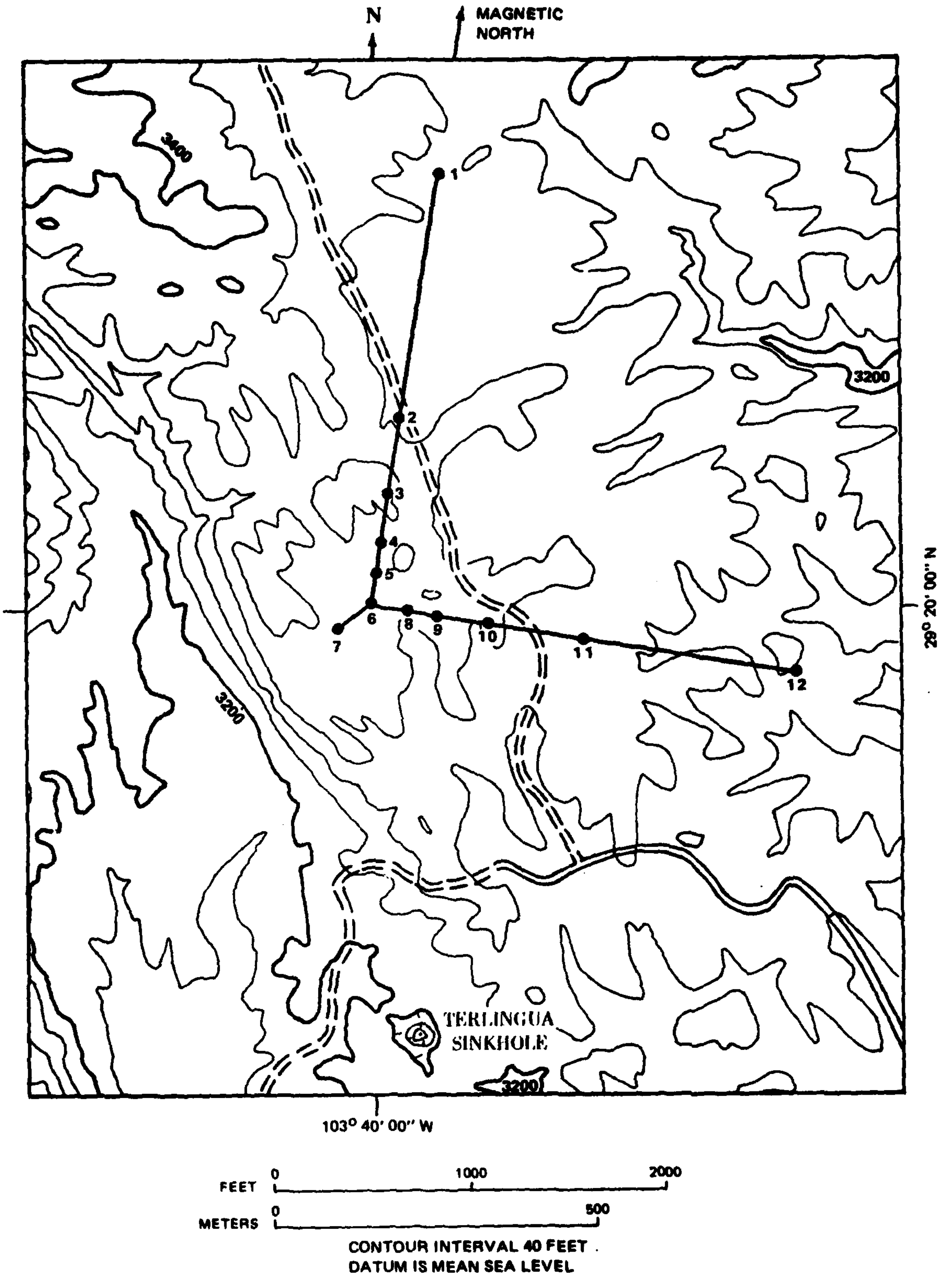

FIGURE 4. SEISMIC ARRAY CONFIGURATION AT LAJITAS, TEXAS

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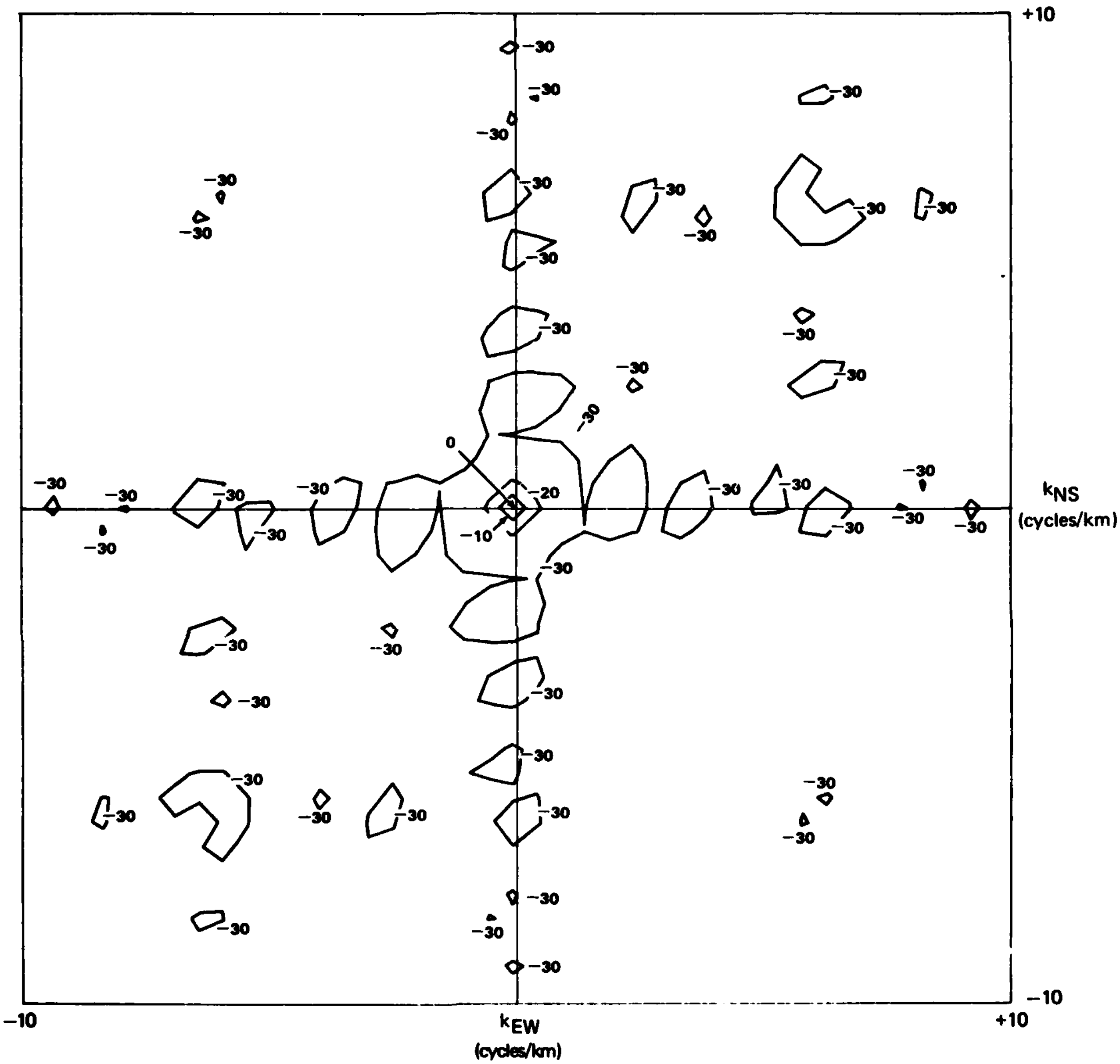

FIGURE 5. MAXIMUM LIKELIHOOD f-k RESPONSE FOR THE LAJITAS ARRAY CONFIGURATION. CONTOUR LEVELS ARE DECIBELS WITH RESPECT TO THE PEAK POWER.

G 12217

III. ANALYSIS OF THE DATA AT THE LAJITAS ARRAY

The system noise of the data collection system appears to be well below the observed seismic noise up to about 10 Hz. Figure 6 shows a comparison of the raw power spectrum (in counts squared per hertz) of seismic noise at seismometer 8, which was consistently quiet, to the power spectrum of noise when the system was dummy loaded at the field amplifiers. The system noise lies below the seismic data up to 20 Hz. However, the data in the 10 to 20 Hz range may be contaminated by nonlinear system noise.

The Lajitas array was extremely sensitive to wind because the operating levels were set at gains of 24 or 30 db, and because the seismometers were sitting on the surface. The digital output would be clipped if the wind speed was much greater than about 5 mph. Even at apparently zero mph wind conditions, individual seismometer stations were noisier than others, probably because of variations in microclimatic conditions from seismometer to seismometer.

An example of low wind (0 to 5 mph) data is shown in figure 7. Even at this quiet time, data from seismometers 6, 10, and 11 are noisy. Seismometer 6 is located near some power poles which may be transmitting wind noise to the ground. Seismometers 10 and 11 are located in open areas, making them vulnerable to gusts of wind. Data from seismometers 1 and 12 contain small spikes which may be caused by distant lightning flashes picked up by the long lengths of cable at these stations. Long-period fluctuations are 4-6 second microseisms which are coherent across the array and dominate the appearance of the seismic traces during quiet times. Seismometer 7 was not operating during the time this data sample was recorded.

The power spectra of the noise data defined over the positive frequency axis, were obtained by averaging sixteen blocks of 512 samples in the technique described by Welch (1967). In addition, a Hamming window was applied to the time domain data. During quiet times, these spectra have a characteristic appearance that is stable both in time (figure 8) and space (figure 9). Below 1 Hz, the spectrum is dominated by the microseisms. In the band between 1 and 10 Hz, the power drops from about 10^{-2} to 10^{-5} $m\mu^2$/Hz, a slope of about 30 db per decade. Very stable spectral peaks appear at around 2 Hz and 5 Hz, and a less stable peak occurs at around 3 Hz. The 2 Hz harmonic peaks at about 10^{-3} $m\mu^2$/Hz and the 5 Hz harmonic peaks at about 10^{-4} $m\mu^2$/Hz.

A comparison of the spectrum at the Lajitas site to another quiet site spectrum (Queen Creek, Arizona) is shown in figure 10. The data from Queen Creek (Fix, 1972) are representative of typical quiet site spectra. The power spectra at both sites are consistent with each other below 1 Hz. However, in the frequency band from 1 to 10 Hz, the power spectrum at Lajitas is about 10 db lower than at Queen Creek. The 2 and 5 Hz peaks, which are prominent in the Lajitas data, would be buried in the background noise at Queen Creek, if they existed there.

Not all the array seismometer stations are equally quiet, as evident in figure 9. It is likely that station differences are due to the variation in surface conditions near each seismometer. The quietest data are probably

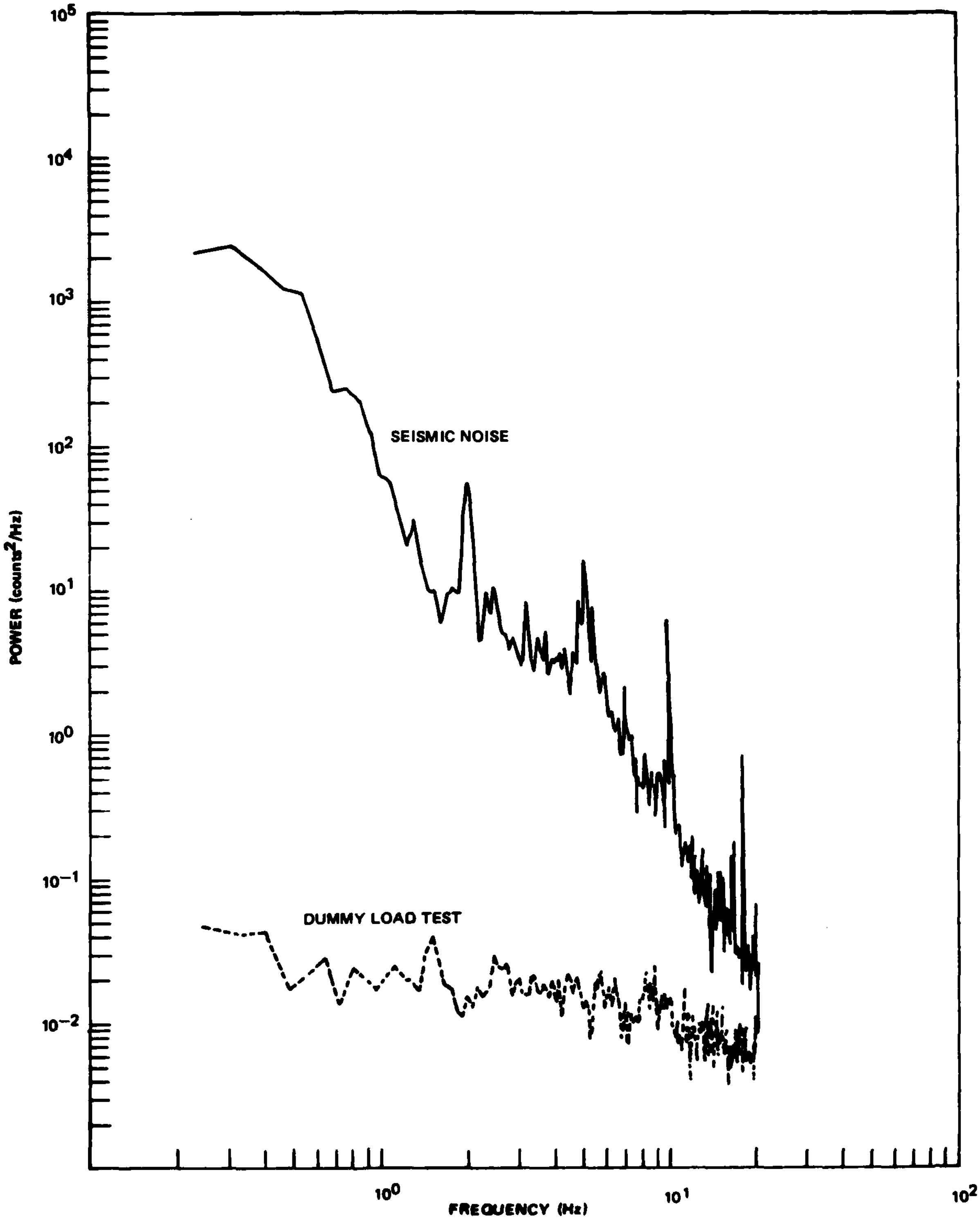

FIGURE 6. COMPARISON OF THE DUMMY LOAD TEST TO SEISMIC NOISE AT SEISMOMETER 8. POWER SPECTRUM IS NOT CORRECTED FOR SYSTEM RESPONSE.

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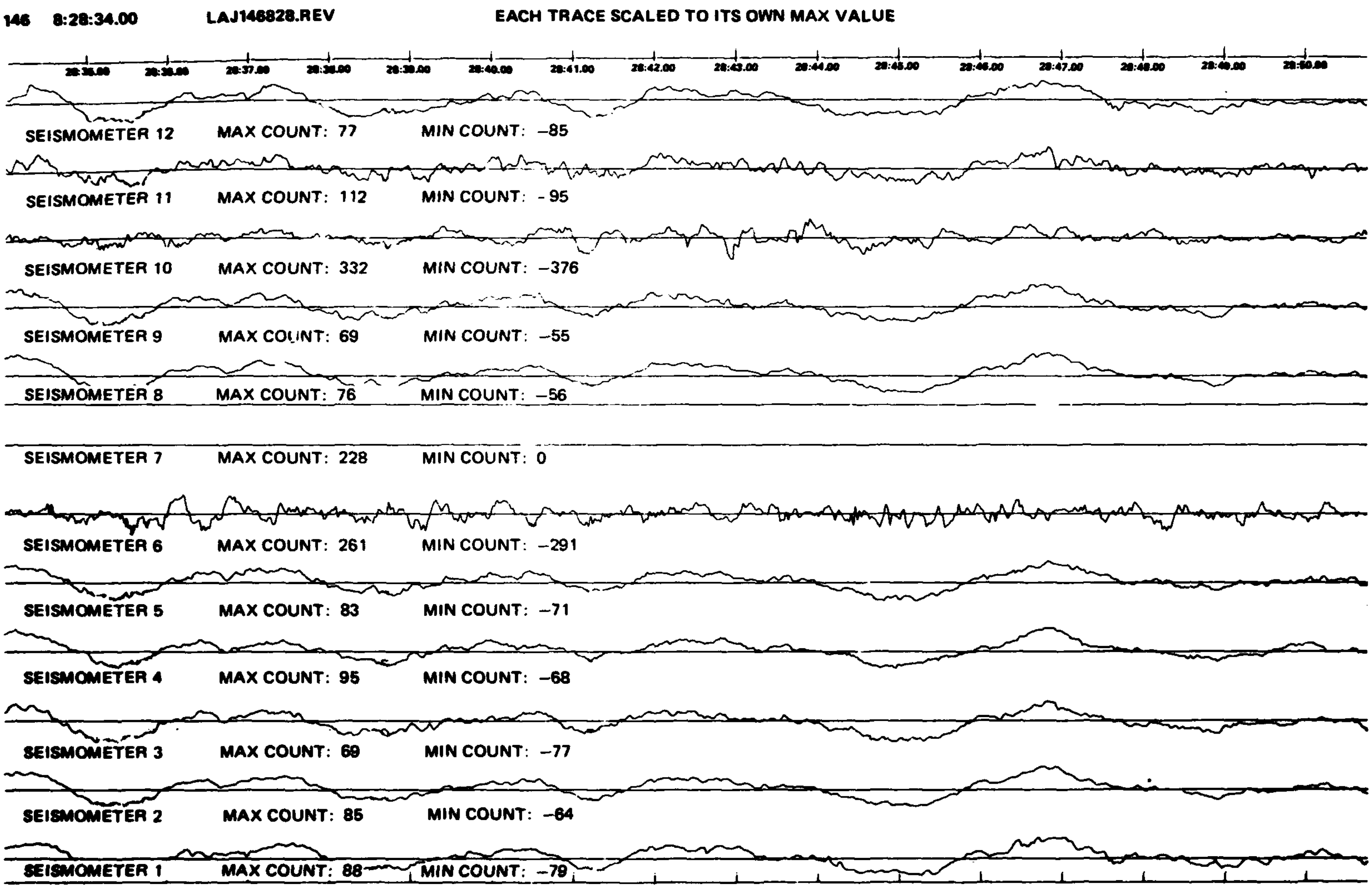

FIGURE 7. SEISMIC TRACES FOR CENTRAL DAYLIGHT SAVINGS TIME 3 a.m., MAY 26, 1981 (8:28:34 UTC, DAY 146). (SEISMOMETER 7 WAS INOPERATIVE).

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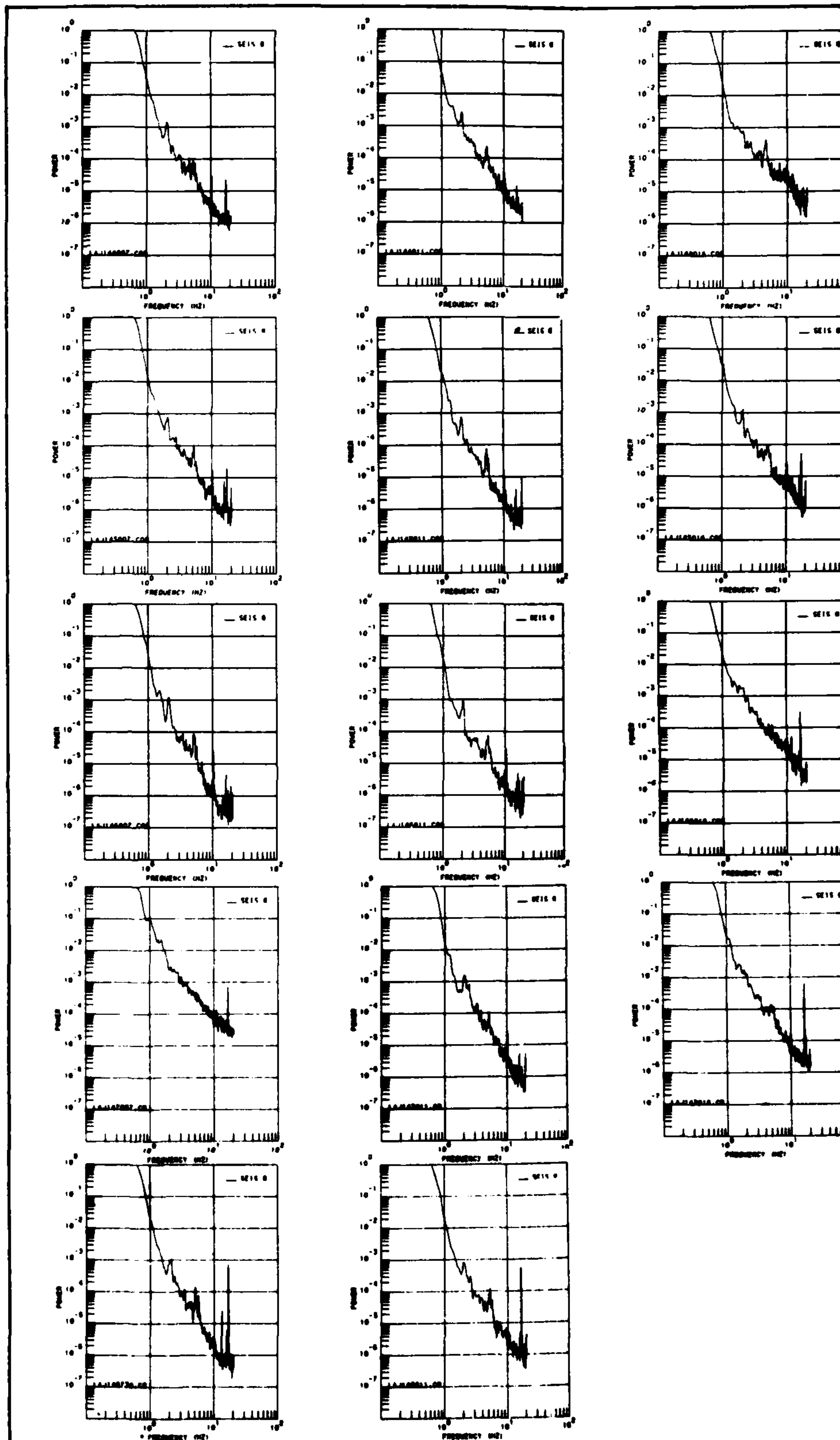


SUNDAY
MAY 24, 1981

MONDAY
MAY 25, 1981

TUESDAY
MAY 26, 1981

WEDNESDAY
MAY 27, 1981

THURSDAY
MAY 28, 1981

2 A.M. 6 A.M. 11 A.M.

LOCAL TIME (CENTRAL DAYLIGHT SAVINGS)

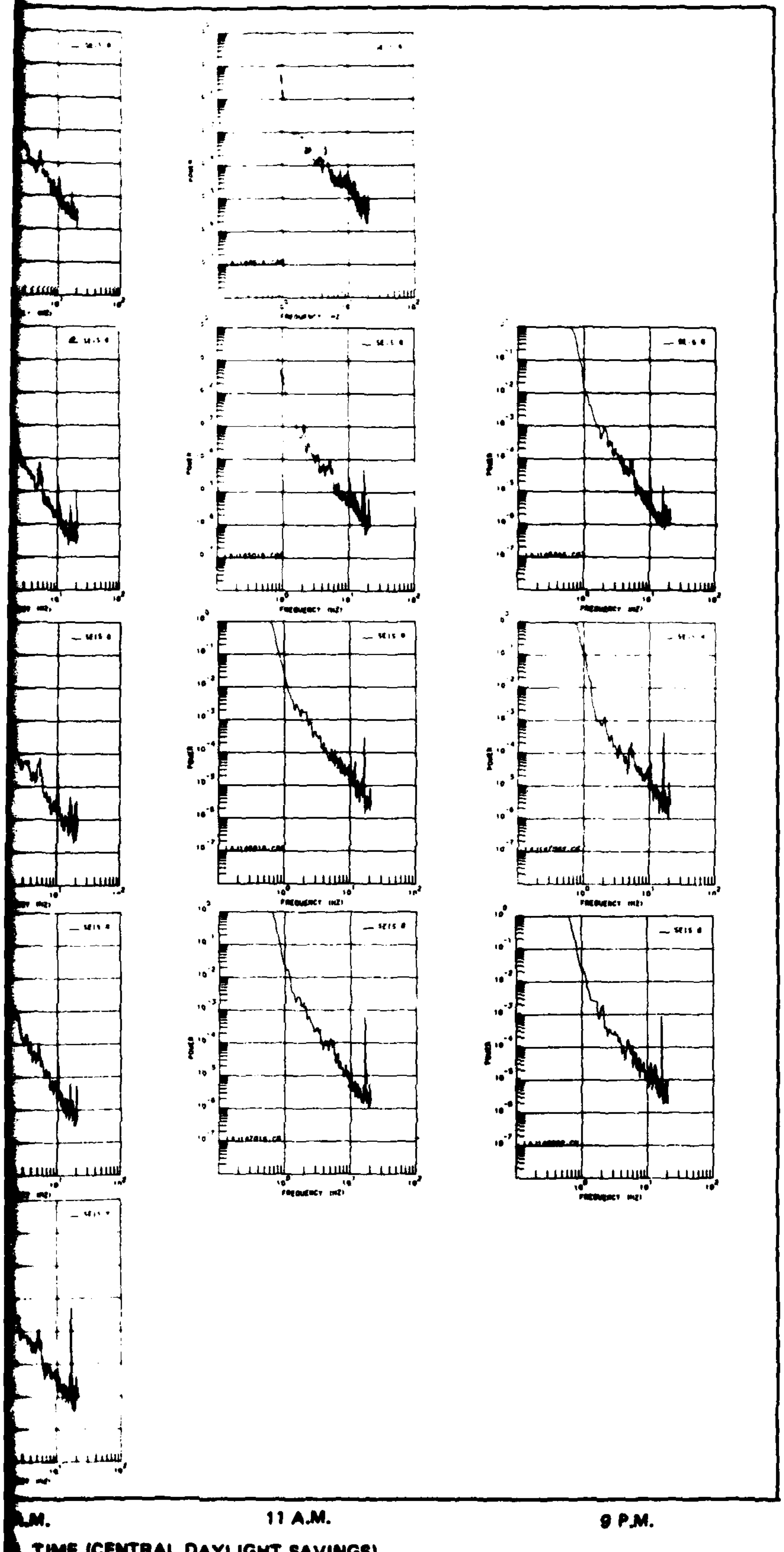


FIGURE 8. VARIATION OF POWER SPECTRA IN TIME AT SEISMOMETER 8 OF THE LAJITAS ARRAY.

G 12220

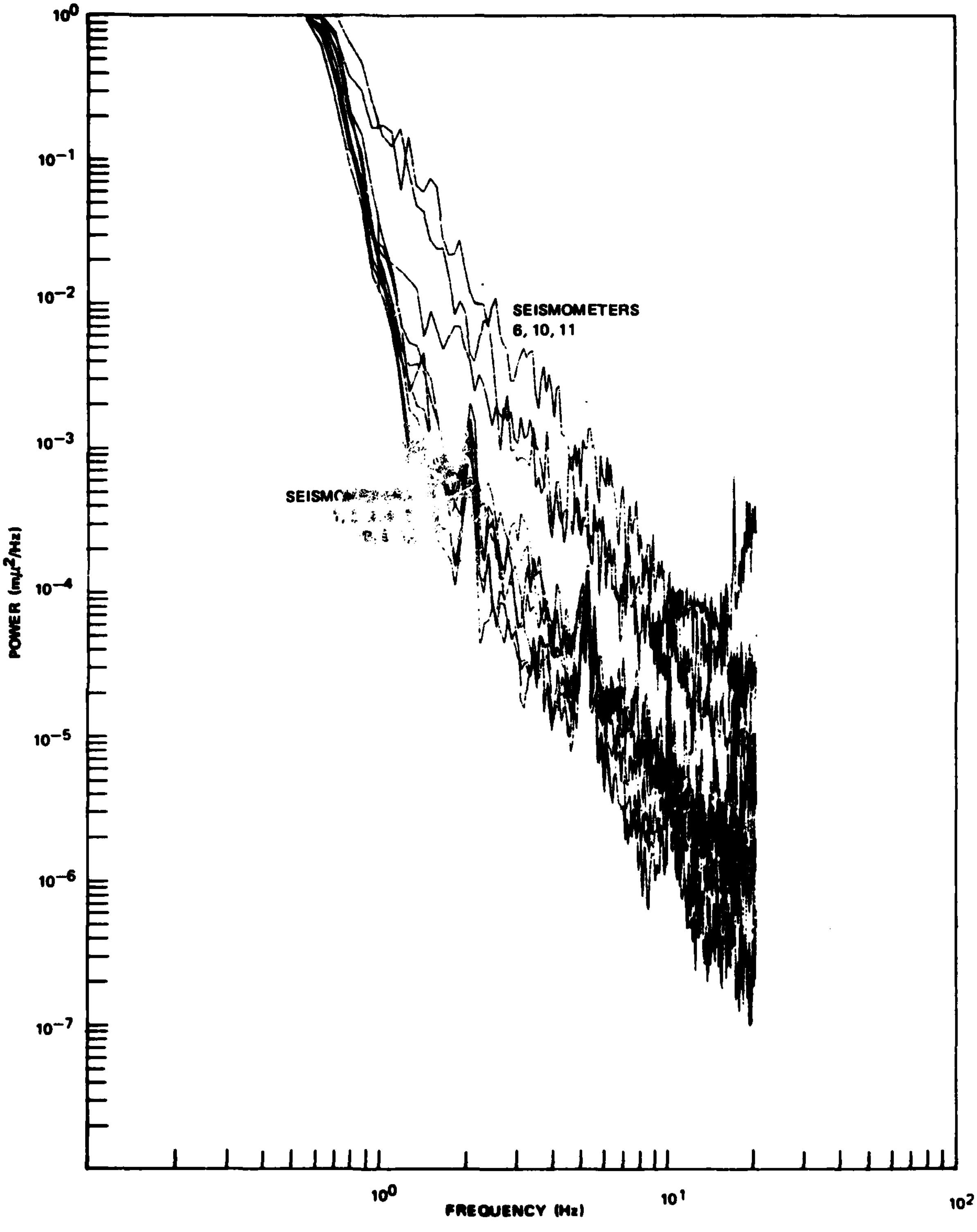


FIGURE 9. COMPARISON OF POWER SPECTRA ACROSS THE LAJITAS ARRAY DURING A QUIET PERIOD ON MAY 26, 1981, 3 a.m. CENTRAL DAYLIGHT SAVINGS TIME (8:28:34 UTC DAY 146)

G 12221

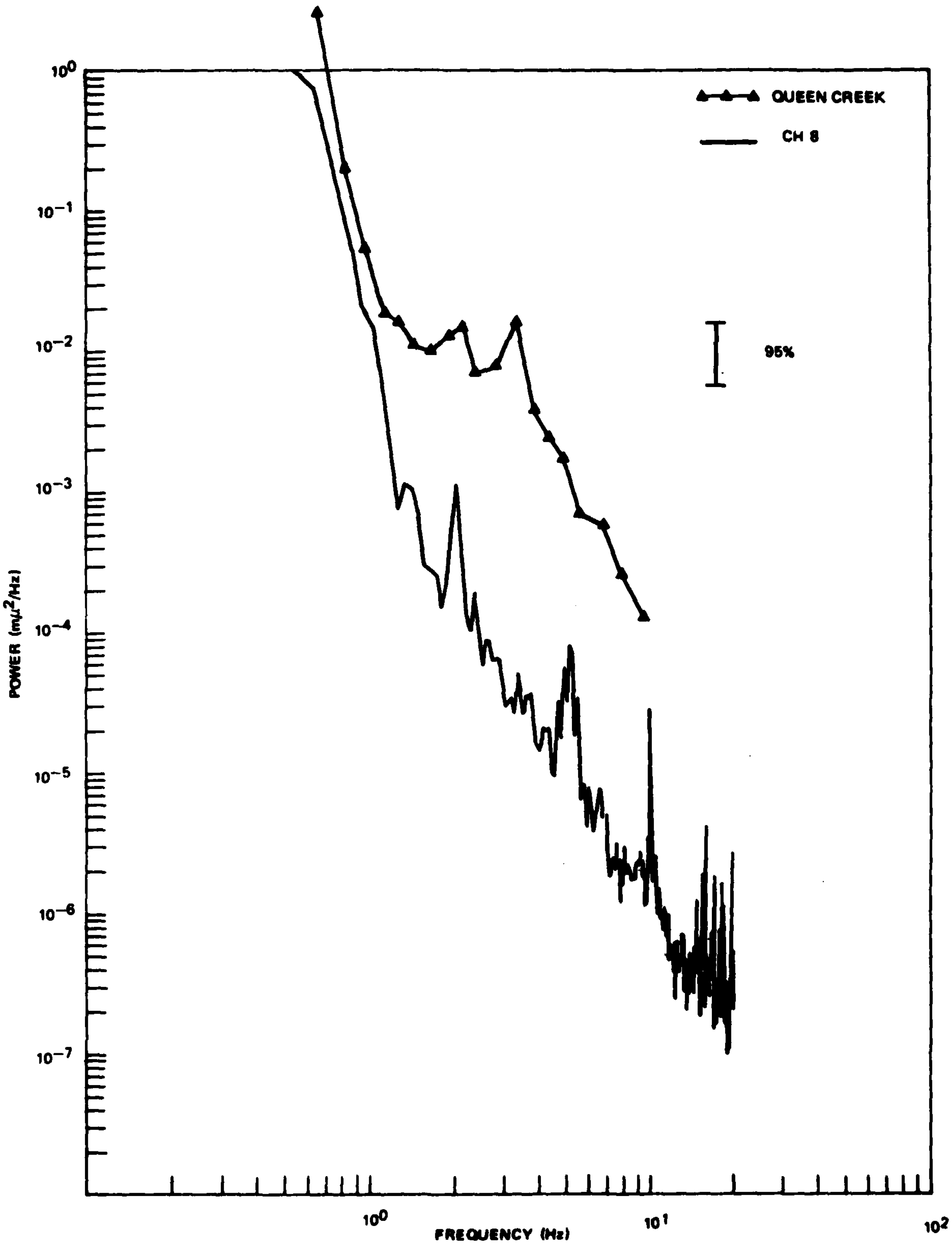


FIGURE 10. REPRESENTATIVE NOISE POWER SPECTRAL DENSITY ESTIMATES AT LAJITAS, TEXAS, DURING A QUIET INTERVAL. QUEEN CREEK NOISE ESTIMATE, FIX, 1972 IS INCLUDED FOR REFERENCE.

G 12120 A

representative of the noise that would be observed in a borehole. This is illustrated by figure 11 which compares the multiple coherence at a quiet station (seismometer 8) to the multiple coherence at a noisy station (seismometer 6). Multiple coherence is a measure of the predictability of the information at a single channel from a linear combination of all the other channels (Bendat and Piersol, 1966). At a quiet station, the noise is very predictable out to about 8 Hz (figure 11a). At a noisy station, the noise is not predictable past about 1 Hz (figure 11b).

Data from seismometer stations with high multiple coherence in the 1 to 10 Hz frequency band were used to compute frequency-wavenumber spectra at the peaks at 2, 3, and 5 Hz. Examples of these are shown in figure 12 (a, b, c). The peaks at 2 and 5 Hz appear to be fairly well organized; the peak at 3 Hz is less so. The direction of propagation in each case appears to be from the north or northeast. This direction may be strongly controlled by the local geology. The phase velocities range from 2 to 4 km/sec. These velocities are close to the resolution limits of the array.

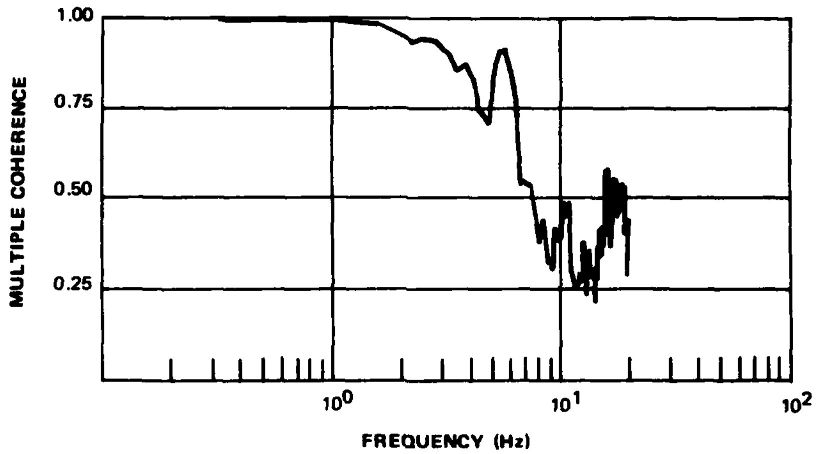
In addition to noise data, about 30 or 40 teleseismic events were recorded during this experiment. Two events are presented here as illustrations of the data obtainable at the Lajitas site.

The first event is a Soviet nuclear explosion on May 25, 1981, located south of Novaya Zemlya (68.182 N, 053.689 E) at a distance of 76°. The origin time of the event was 04:59:57.2 UTC, and the body-wave magnitude was 5.5 as reported in the USGS Preliminary Determination of Epicenters. Figure 13 shows the seismic traces for this event at a quiet station (2) and a noisy station (11). Data from seismometer 2 are clipped slightly at the third minimum. Traces from the seven quietest stations (seismometers 1, 2, 3, 5, 8, 9, and 12) were summed and averaged. The first cycle of the P-wave arrival taken from the summed traces is shown in figure 14. This window was zeroed out to 1024 samples and then Fourier transformed into the frequency domain.

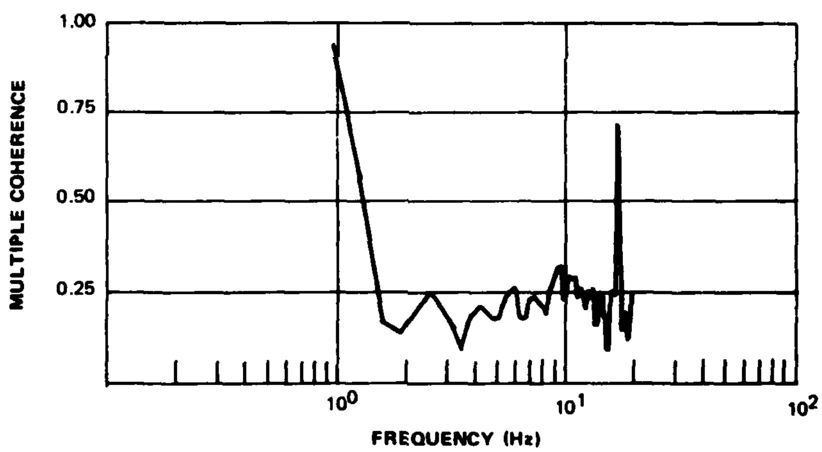
The amplitude spectrum for the summed P-wave of the Soviet explosion is shown in figure 15. The microseisms appear to be present in the signal data. In addition, there is a spectral notch at about 4 Hz that is suggestive of pP interference with P caused by the shallow burial depth of the explosion. Note that this information would have been lost at Queen Creek.

For comparison is an earthquake at Sakhalin Island on May 25, 1981 (46.16 N, 141.84 E; origin time 09:19:41.3 UTC; distance 82°; depth 33 km; body-wave magnitude 5.1). The seismic traces for seismometers 2 and 11 are shown in figure 16. The same averaging technique was applied to this data as for the Soviet explosion. The windowed P-wave pulse is shown in figure 17, and the corresponding amplitude spectrum is shown in figure 18. Note that there is no spectral notch comparable to the one in the explosion spectrum.

Both event power spectra are compared to a spectrum of noise averaged over data collected at seven stations in figure 19. Note here that in the 1 to 10 Hz frequency band, both signal and noise spectra drop in power at a similar rate. This suggests that, given a sufficiently high quality system configuration, useful information concerning the properties of moderate to weak strength seismic sources can be obtained at sites such as Lajitas.



(a)



(b)

FIGURE 11. MULTIPLE COHERENCE AT SEISMOMETER 8 (a) AND SEISMOMETER 6 (b) FOR 28 MAY, 1981 AT 3 a.m. (146 8:28:34 UTC).

G 12222

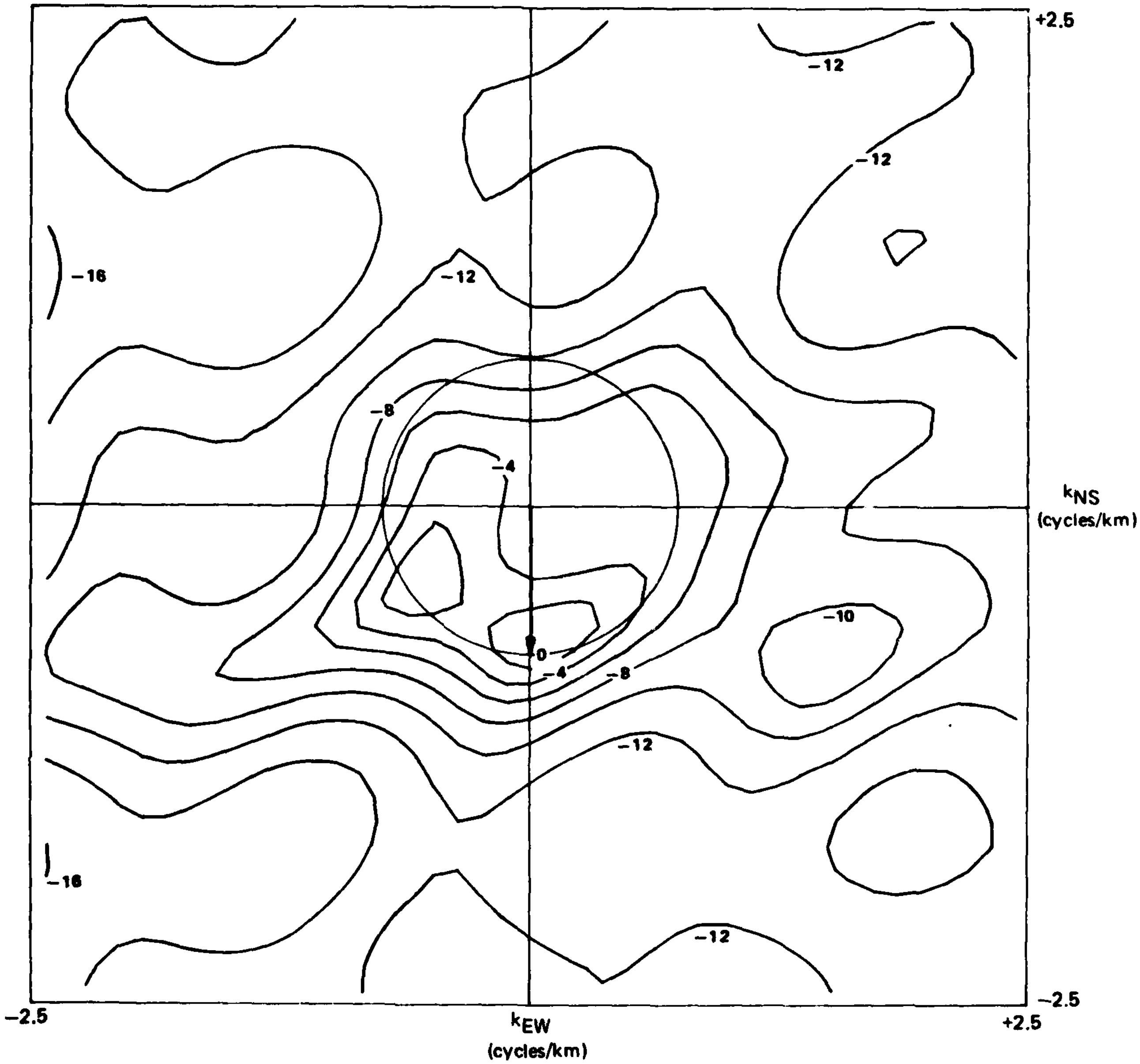


FIGURE 12a. MAXIMUM LIKELIHOOD f-k SPECTRUM AT 2.04 Hz FOR MAY 26, 1981 AT 3 a.m. (8:28:34 UTC DAY 146). THE PEAK POWER IS AT VELOCITY 2.71 km/sec AND AZIMUTH 180°. THE CONTOUR INTERVAL IS 2 DECIBELS WITH RESPECT TO THE PEAK POWER.

G 12223

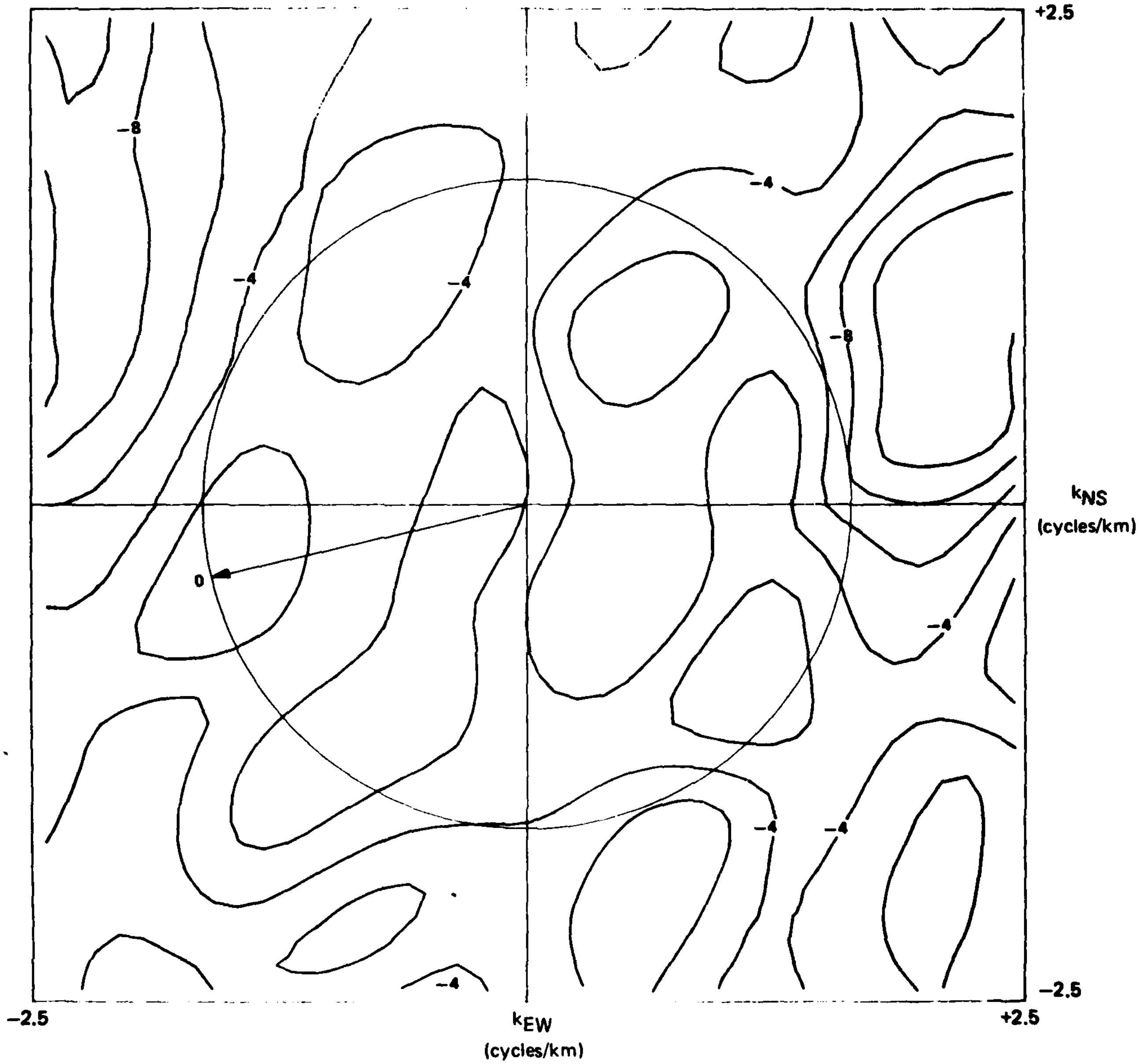


FIGURE 12b. MAXIMUM LIKELIHOOD f-k SPECTRUM AT 3.13 Hz FOR MAY 26, 1981 AT 3 a.m. (8:28:34 UTC DAY 146). THE PEAK POWER IS AT VELOCITY 1.88 km/sec AND AZIMUTH 257°. THE CONTOUR INTERVAL IS 2 DECIBELS WITH RESPECT TO THE PEAK POWER.

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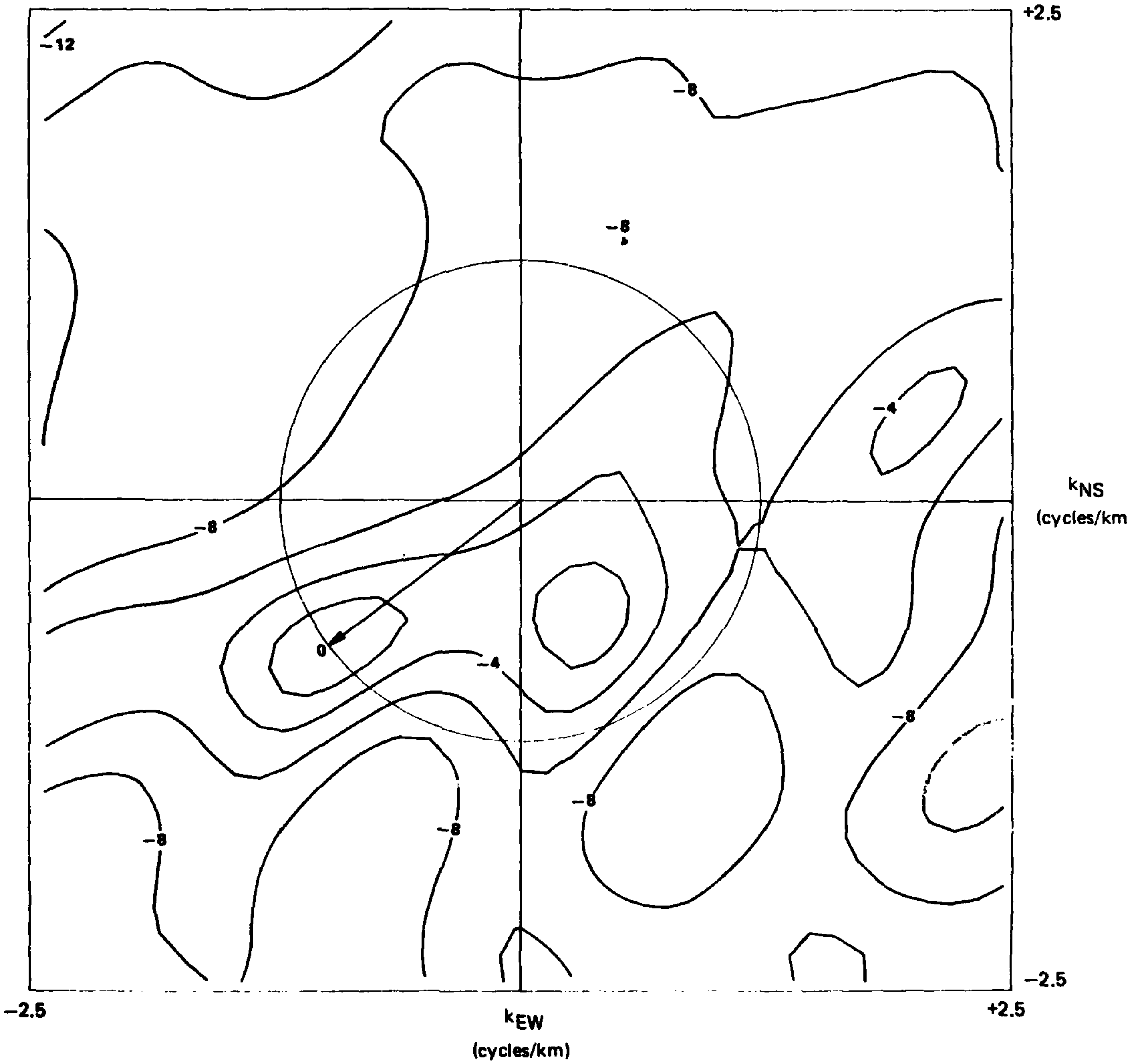

FIGURE 12c. MAXIMUM LIKELIHOOD f-k SPECTRUM AT 4.93 Hz FOR MAY 26, 1981 AT 3 a.m. (8:28:34 UTC DAY 146). THE PEAK POWER IS AT VELOCITY 3.95 km/sec AND AZIMUTH 233°. THE CONTOUR INTERVAL IS 2 DECIBELS WITH RESPECT TO THE PEAK POWER.

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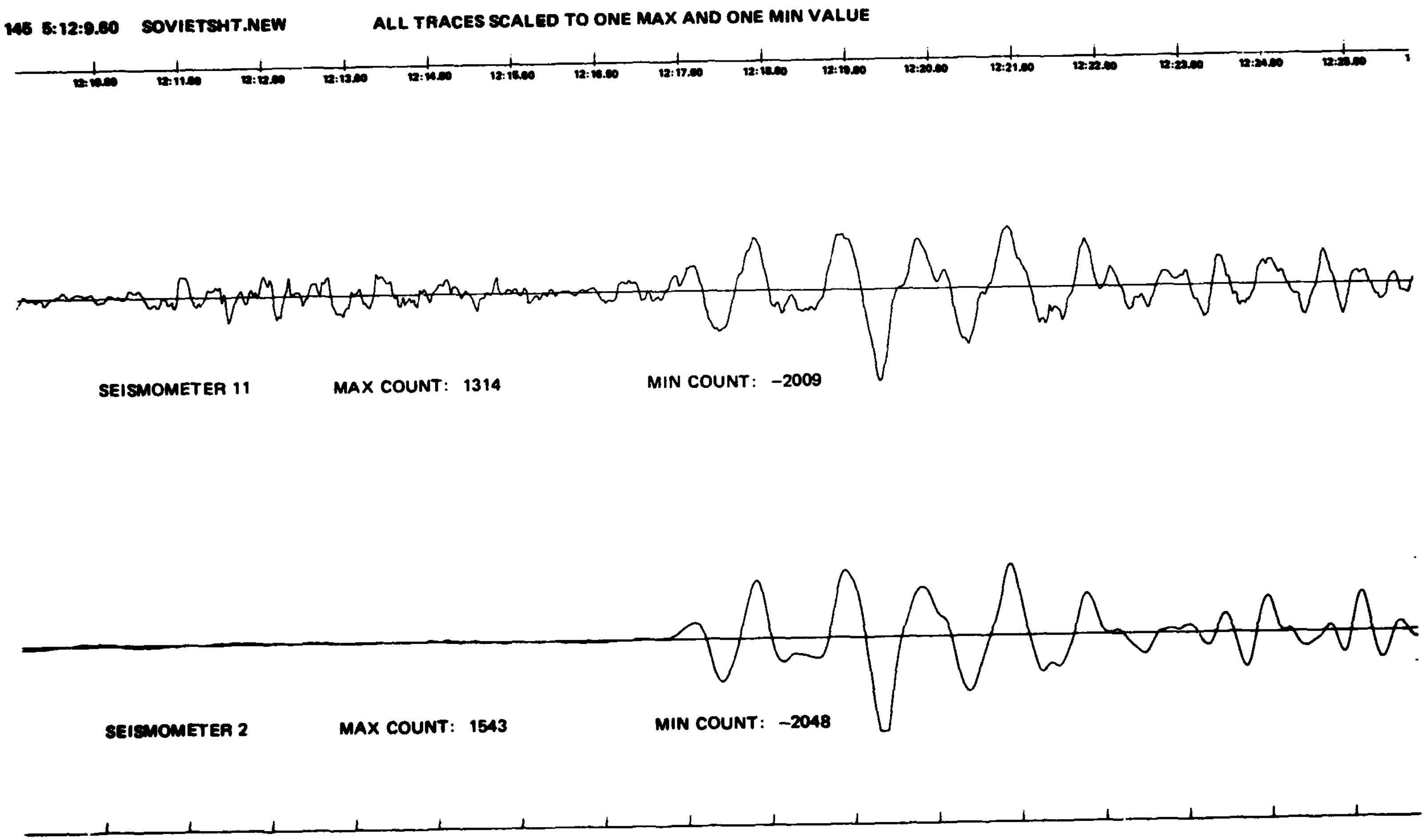

FIGURE 13. SEISMIC TRACES OF THE USSR NUCLEAR EXPLOSION ON MAY 25, 1981 AT SEISMOMETERS 2 AND 11. THE ORIGIN TIME IS 04:59:57.2 UTC AND THE LOCATION IS SOUTH OF NOVAYA ZEMLYA (68.182N, 053.689E) AT A DISTANCE OF 76°. THE BODY-WAVE MAGNITUDE IS 5.5.

G 12226

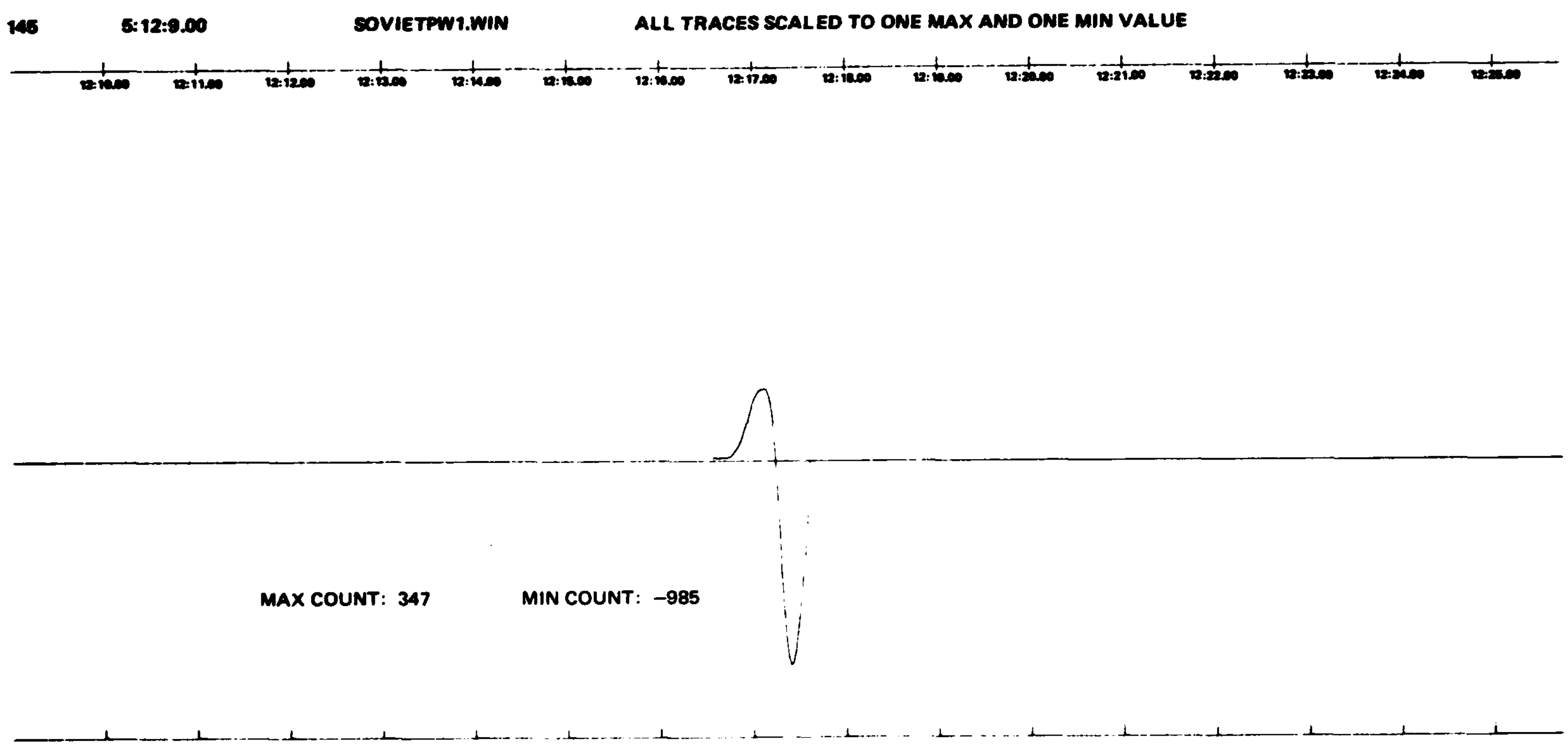

FIGURE 14. P-WAVE WINDOW OF THE USSR NUCLEAR EXPLOSION ON MAY 25, 1981. THE SEISMIC TRACE IS THE AVERAGE OF DATA COLLECTED AT SEVEN SEISMOMETERS (1, 2, 3, 5, 8, 9, AND 12) OF THE LAJITAS ARRAY.

G 12227

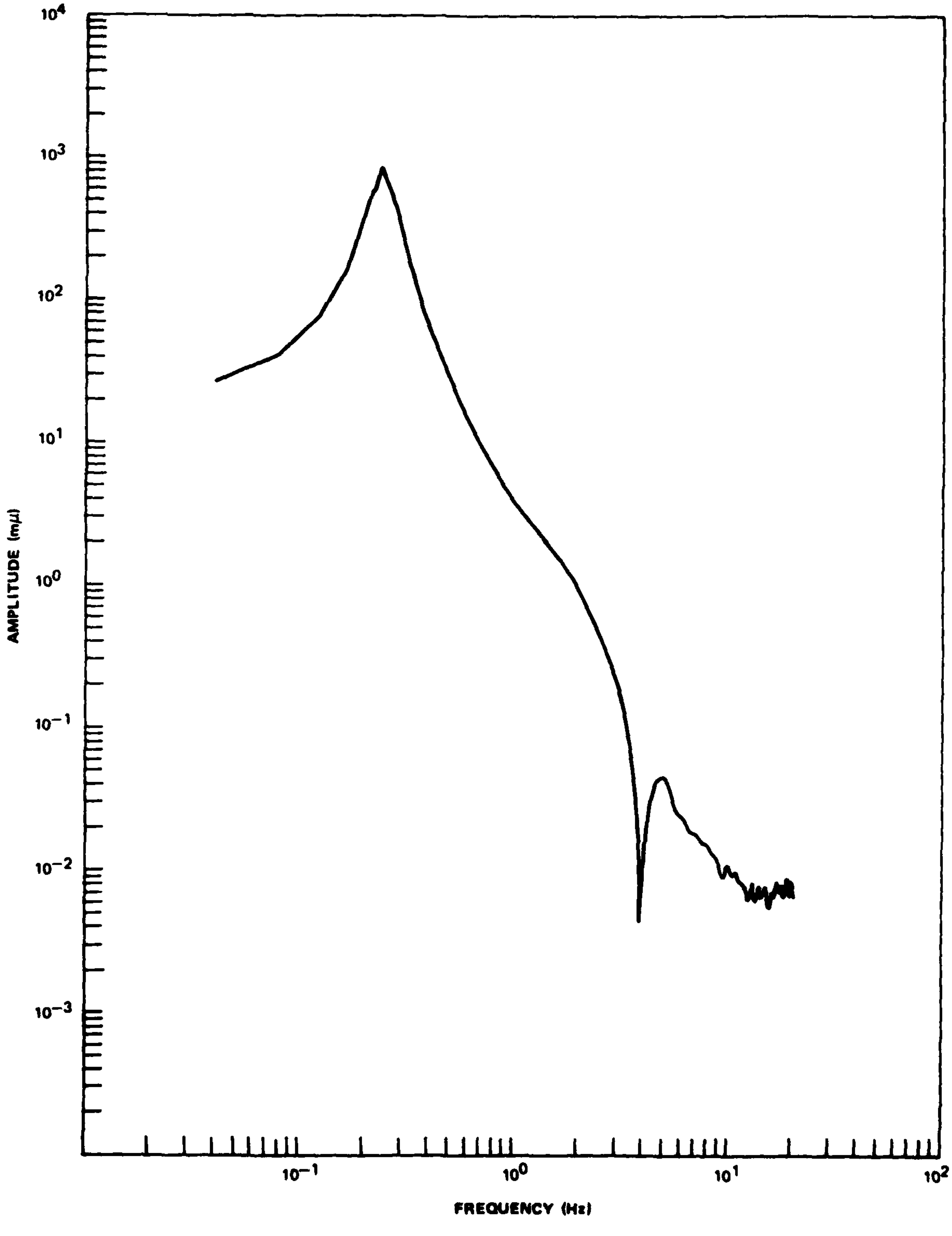

FIGURE 15. AMPLITUDE SPECTRUM OF THE AVERAGED P-WAVE SIGNAL FROM THE USSR NUCLEAR EXPLOSION ON MAY 25, 1981 (SEE FIGURE 14).

G 12228

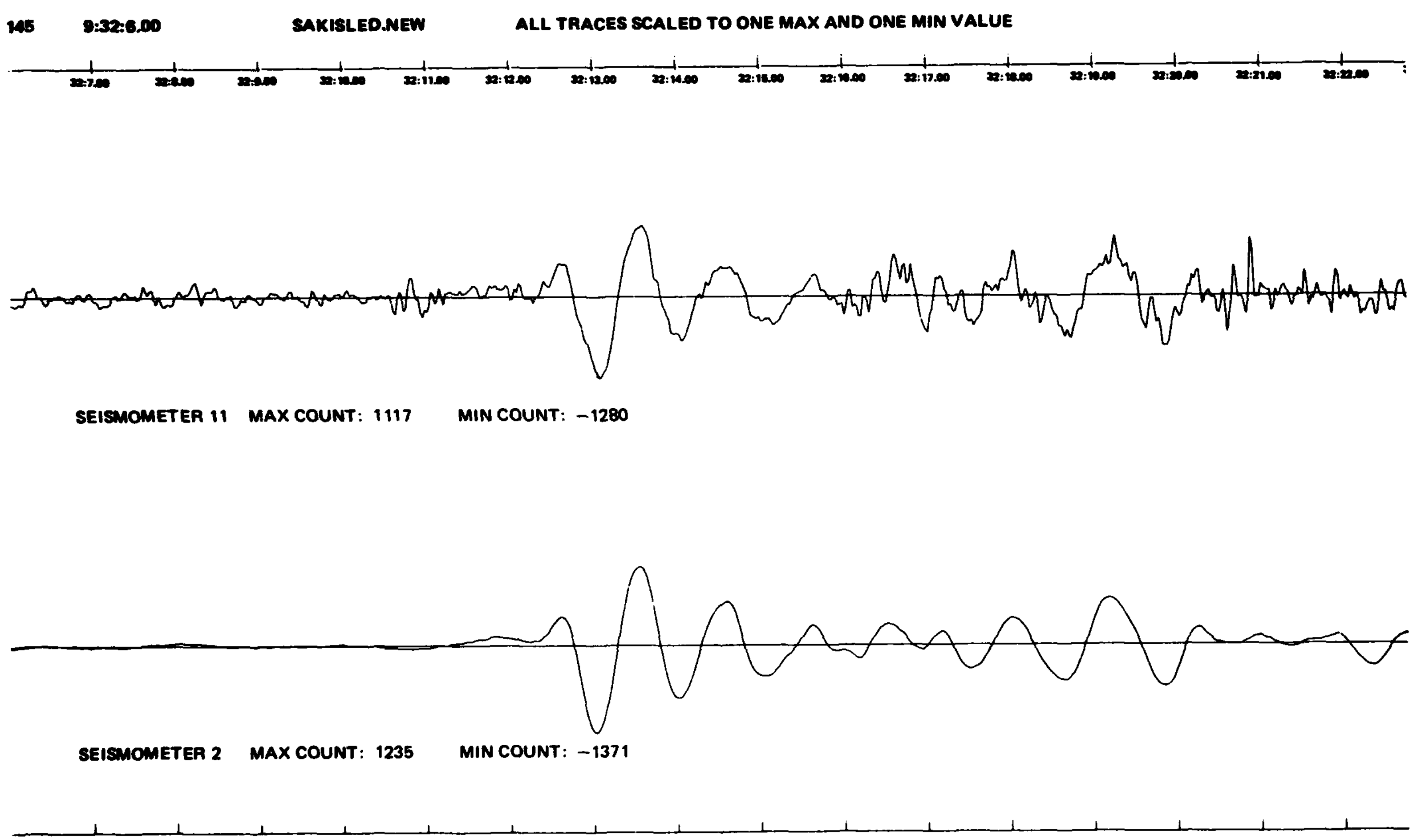

FIGURE 16. SEISMIC TRACES OF SAKHALIN ISLAND EARTHQUAKE ON MAY 25, 1981 AT SEISMOMETERS 2 AND 11. THE ORIGIN TIME IS 09:19:41.3 UTC. THE EPICENTER IS AT 46.16 N, 141.84 E, A DISTANCE OF 82°. THE DEPTH OF FOCUS IS 33 km AND THE BODY-WAVE MAGNITUDE IS 5.1.

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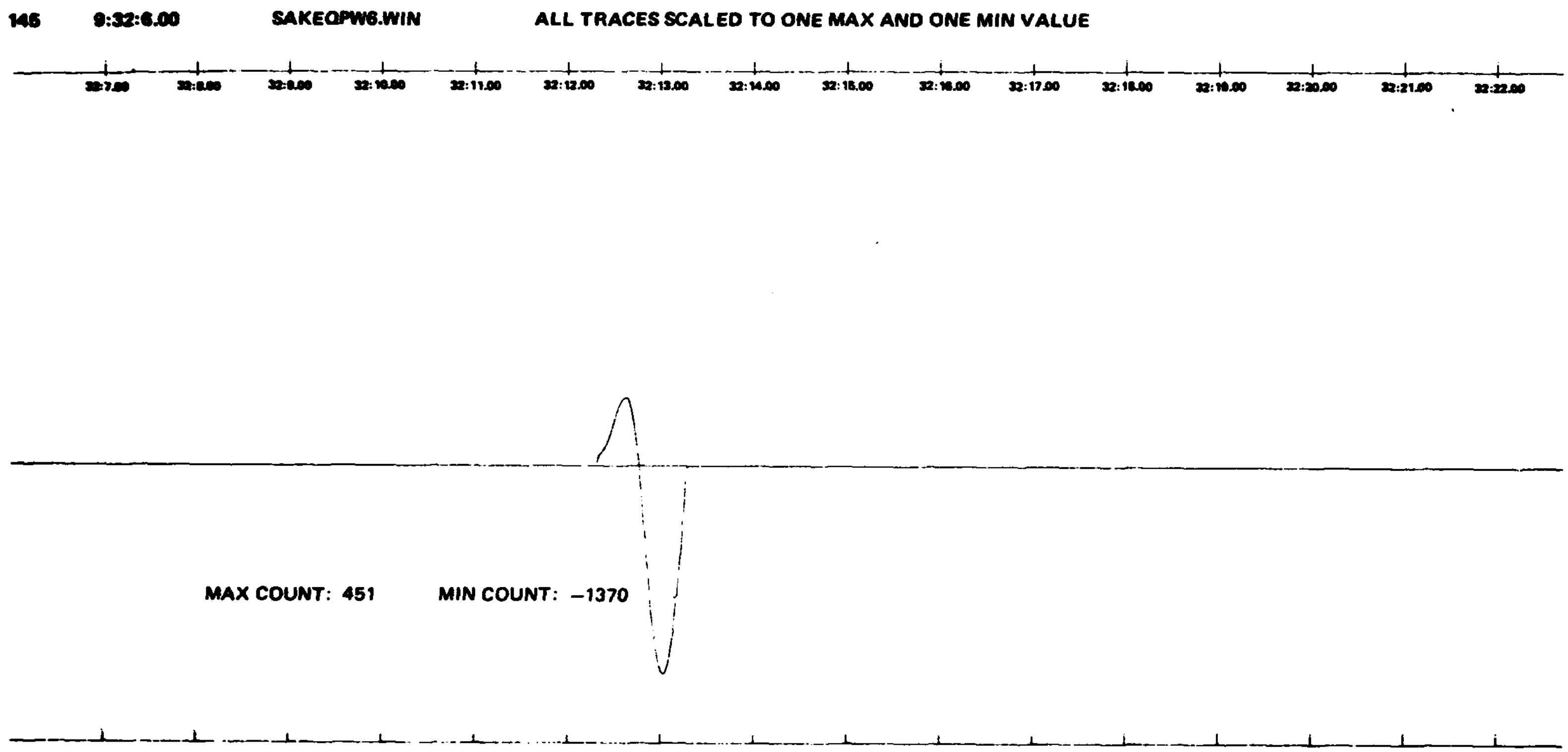

FIGURE 17. P-WAVE WINDOW OF THE EARTHQUAKE AT SAKHALIN ISLAND ON MAY 25, 1981. THE SEISMIC TRACE IS THE AVERAGE OF DATA COLLECTED AT SEVEN SEISMOMETERS (1, 2, 3, 5, 8, 9 AND 12) OF THE LAJITAS ARRAY.

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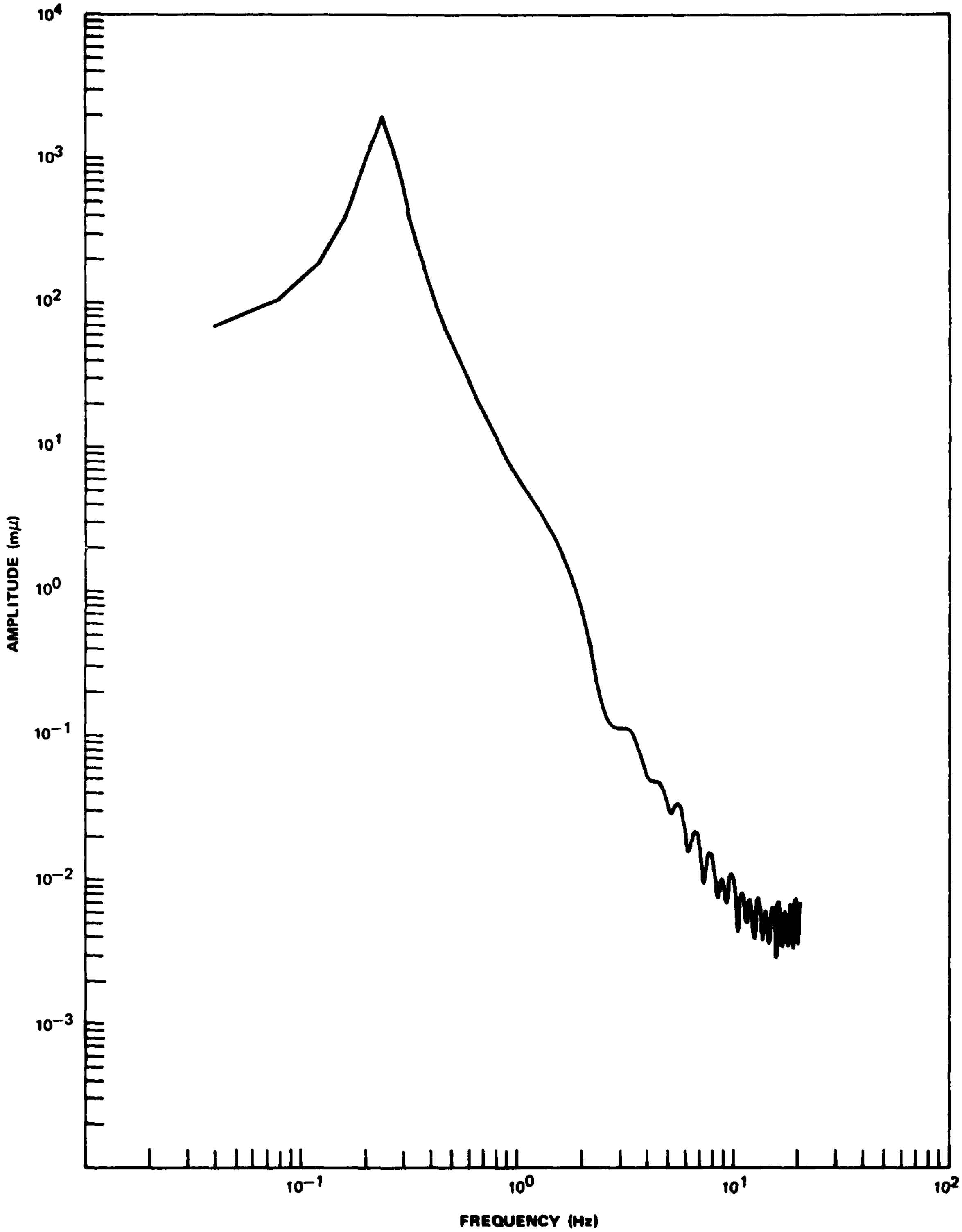

FIGURE 18. AMPLITUDE SPECTRUM OF THE AVERAGED P-WAVE SIGNAL FROM THE SAKHALIN ISLAND EARTHQUAKE ON MAY 25, 1981 (SEE FIGURE 17). G 12231

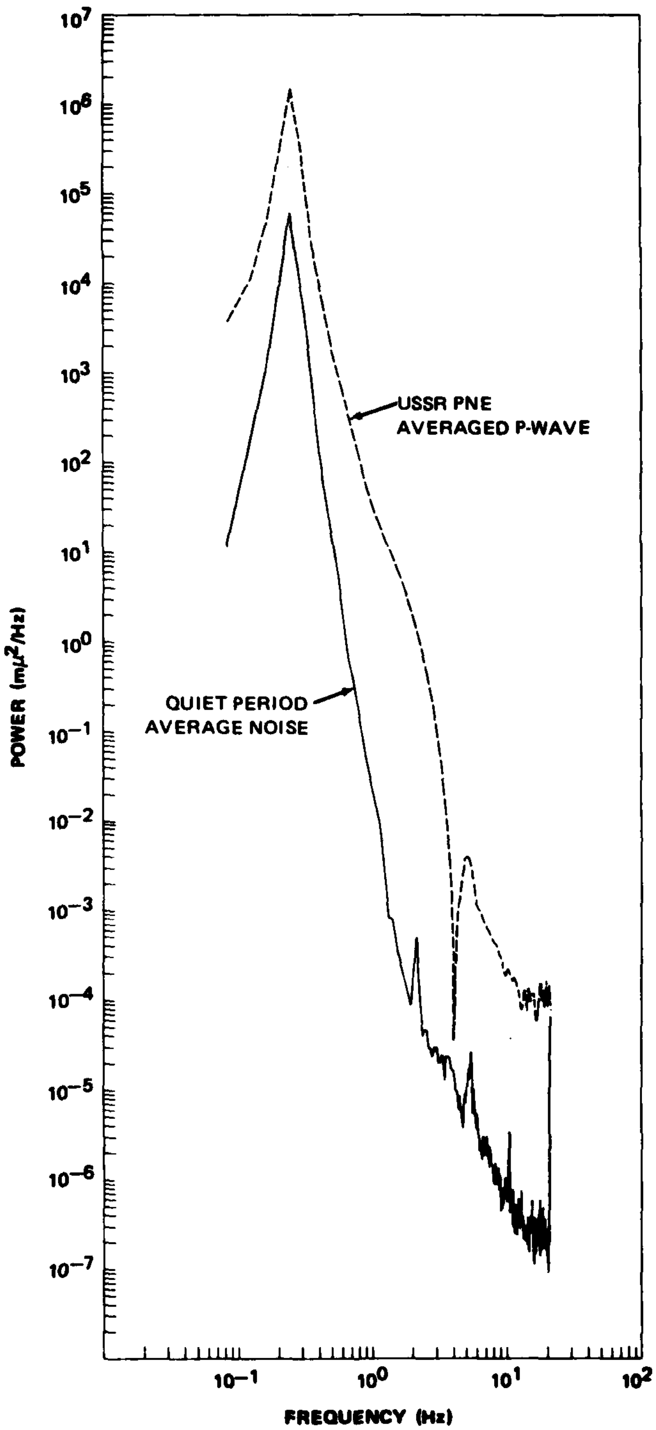

FIGURE 19a. COMPARISON OF THE POWER SPECTRA OF THE AVERAGED P-WAVE SIGNAL FROM THE USSR NUCLEAR EXPLOSION, ADJUSTED FOR WINDOW LENGTH, TO QUIET PERIOD NOISE AT 2 a.m., MAY 25, 1981, AVERAGE OF DATA COLLECTED AT SEVEN SEISMOMETERS.

G 12232

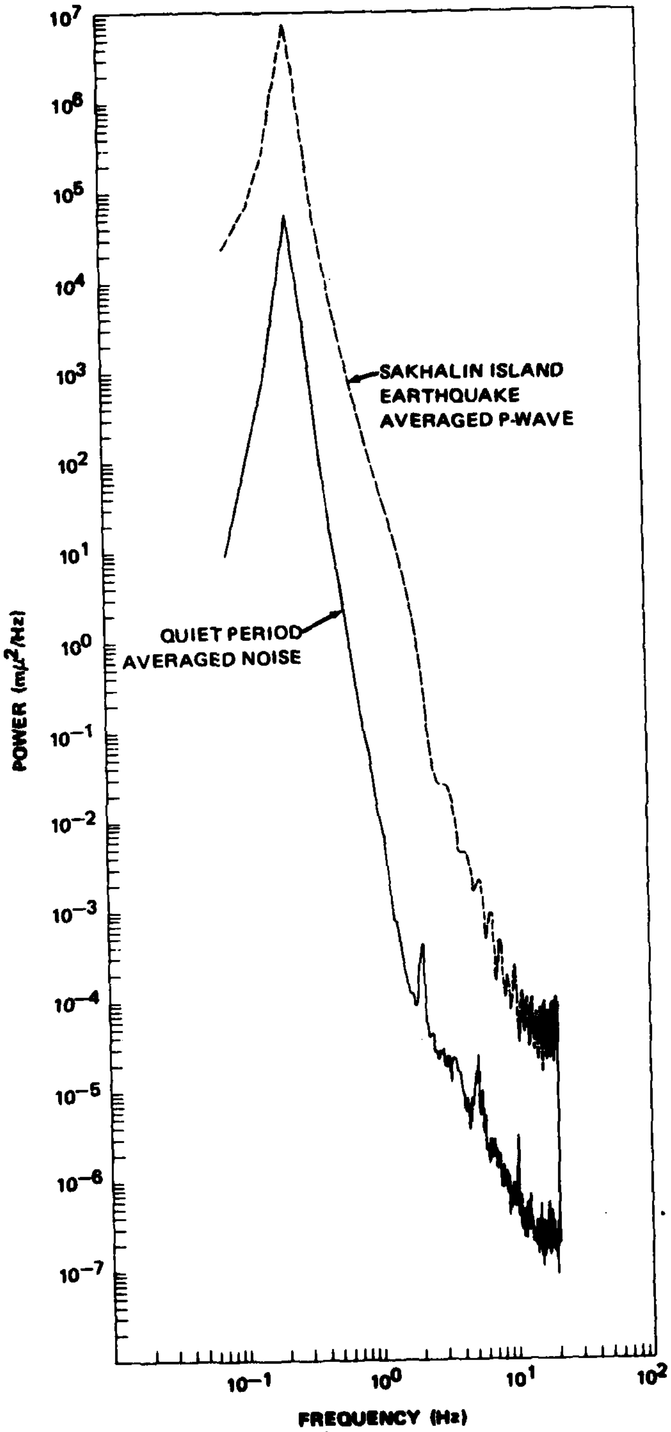

FIGURE 19b. COMPARISON OF THE POWER SPECTRA OF THE AVERAGED P-WAVE SIGNAL FROM THE SAKHALIN ISLAND EARTHQUAKE, ADJUSTED FOR WINDOW LENGTH, TO QUIET PERIOD NOISE AT 2 a.m., MAY 25, 1981, AVERAGE OF DATA COLLECTED AT SEVEN SEISMOMETERS.

G 12233

SUMMARY AND CONCLUSIONS

The power spectra of the noise data are stable in both time and space.

Below about 1.0 Hz, the spectra have roughly the same power levels as spectra at other seismically quiet sites (e.g., Queen Creek, Arizona). This fact implies that the earth noise in the 0.1-1.0 Hz range is dominated by oceanically-generated body waves and higher mode Rayleigh waves (4-6 second microseisms).

There are two characteristic spectral peaks at 2 Hz and 5 Hz in the Lajitas data which would be buried at sites such as Queen Creek. The origins of these peaks are not known. However, they appear to be well-organized over dimensions of a kilometer and propagate from the north and northeast at phase velocities which are significantly less than the local P-wave velocities. These velocities suggest that local and near-regional noise sources dominate the earth noise spectrum in the 1-10 Hz band even at sites as quiet as Lajitas. If this is true, it should be possible to find other sites where the earth noise levels at frequencies greater than 1.0 Hz are at least as low as those observed at Lajitas. In addition, the state of organization of the 2 Hz and 5 Hz peaks suggests that linear multichannel filtering could be used to further enhance signal-to-noise ratios in the 1-10 Hz band at sites such as Lajitas.

In the 1-10 Hz band, the noise spectra from this site are about 10 db lower than spectra previously reported for other quiet sites, represented by the Queen Creek, Arizona, data (Fix, 1972). The comparison of explosion signal spectral estimates to noise spectral estimates strikingly illustrates the potential value of utilizing such ultra-quiet sites in a network for monitoring underground nuclear tests. Clearly, information important to the determination of the properties of seismic sources of moderate to weak strength can be observed in the 1-10 Hz band at sites such as Lajitas, even at large teleseismic distances. A few rough calculations bear out this observation. In figure 20, we compare hypothetical teleseismic P-wave displacement spectra for underground nuclear explosions of 50, 10, and 1 kt, to the background noise observed at Lajitas. The 50 kt spectrum is drawn to correspond to the spectrum of the Soviet nuclear explosion shown in figure 19a. The 10 kt and 1 kt spectra are drawn assuming that the corner frequency follows a -0.2 scaling law. The important point to note is that, by utilizing seismically ultra-quiet sites, it may be possible to obtain useful source data at teleseismic distances for explosions whose yields are as low as 1 kt or so.

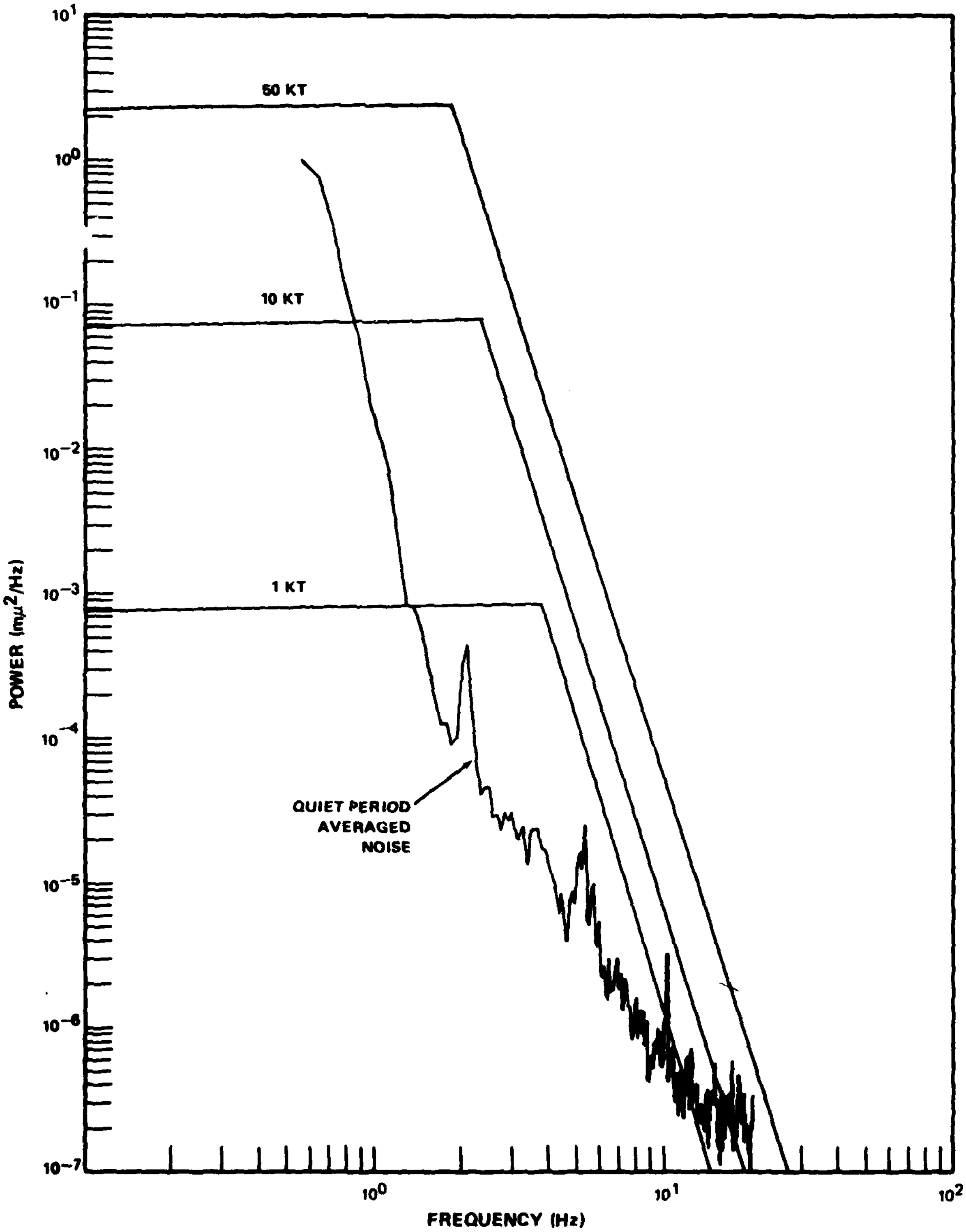

FIGURE 20. COMPARISON OF THEORETICAL P-WAVE DISPLACEMENT SPECTRA FOR UNDERGROUND NUCLEAR EXPLOSIONS TO A REPRESENTATIVE NOISE SPECTRUM AT LAJITAS. THE NOISE DATA ARE THE AVERAGE OF DATA COLLECTED AT SEVEN SEISMOMETERS.

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RECOMMENDATIONS

Based upon our studies over the last two years, we now believe that a number of sites as quiet as, or quieter than, Lajitas can be found on the North American continent and at overseas locations. A search for such ultra-quiet sites should be implemented as soon as possible. Potential ultra-quiet noise sites should be documented and placed into inventory for future use.

An investigation should be undertaken to assess the feasibility of utilizing small aperture arrays in ultra-quiet locations to aid in determining the properties of weak-to-intermediate-strength seismic sources. The bandwidth of the instrumentation should be extended to at least 30 Hz. This investigation should involve the deployment of suitably designed sensor systems in an array near the site of our noise study. Issues to be addressed should include: (1) an assessment of the observed signal-to-noise ratios as a function of frequency and magnitude; (2) an assessment of the use of linear multichannel operators to enhance signal-to-noise ratios at frequencies greater than 1 Hz; (3) an evaluation of the use of extended bandwidth data to characterize seismic sources; and (4) development of requirements for the design and deployment of future extended bandwidth arrays, should the results of the investigation justify such systems.

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